

Scar Definition Technologies for Treatment of Atrial and Ventricular Arrhythmias

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Presenter Disclosure Information

- Equity Interest: Lexmed, MRI Interventions
 - Grant Support: RO1 HL094610
 - Consulting Fees: Zoll Circulation
 - Potential Royalty: Imricor
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- Off label use: MRI of patients with implanted devices; Gadolinium for cardiac studies

Delayed Enhancement MRI

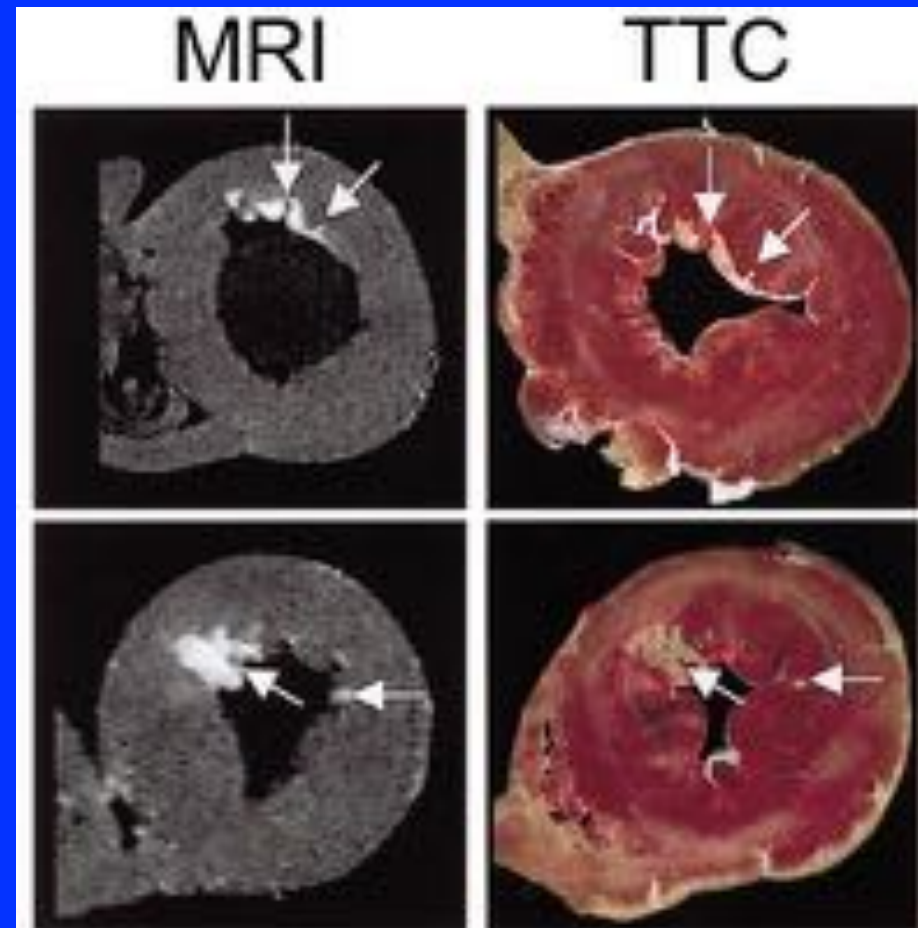
- Detailed imaging of scar and viable myocardium
- Gadolinium Contrast
- Extensively validated
- High spatial resolution

Lima, J.A., et al. *Circulation*, 1995. **92**(5): p. 1117-25.

Kim, R.J., et al. *NEJM*, 2000. **343**(20): p. 1445-53.

Kim RJ, et al: *Circulation* 1999;100;1992-2002

Ashikaga et al. *Circ Res*, 2007. **101**: p. 939-47



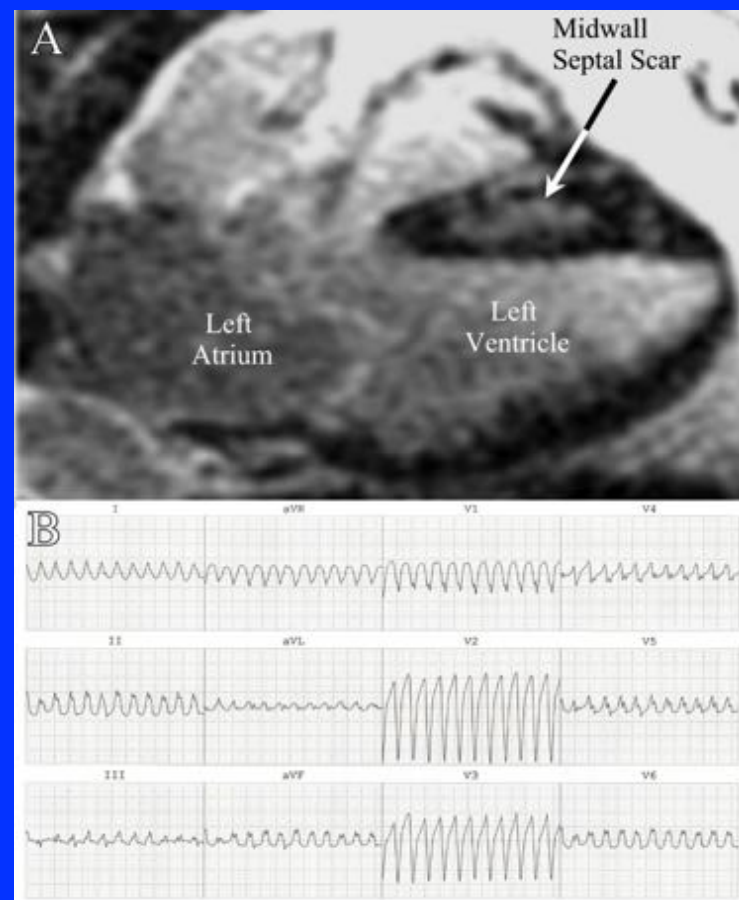
Non-Ischemic Cardiomyopathy

Idiopathic Dilated Cardiomyopathy

- LV (or biventricular) dysfunction after exclusion of other causes of myopathy
 - 46,000 hospitalizations and 10,000 deaths per year
 - Primary indication for cardiac transplantation
- CMR
 - Mid-wall or patchy scar
 - Mid-wall scar is seen in 30% of patients with idiopathic dilated cardiomyopathy

Midwall Fibrosis

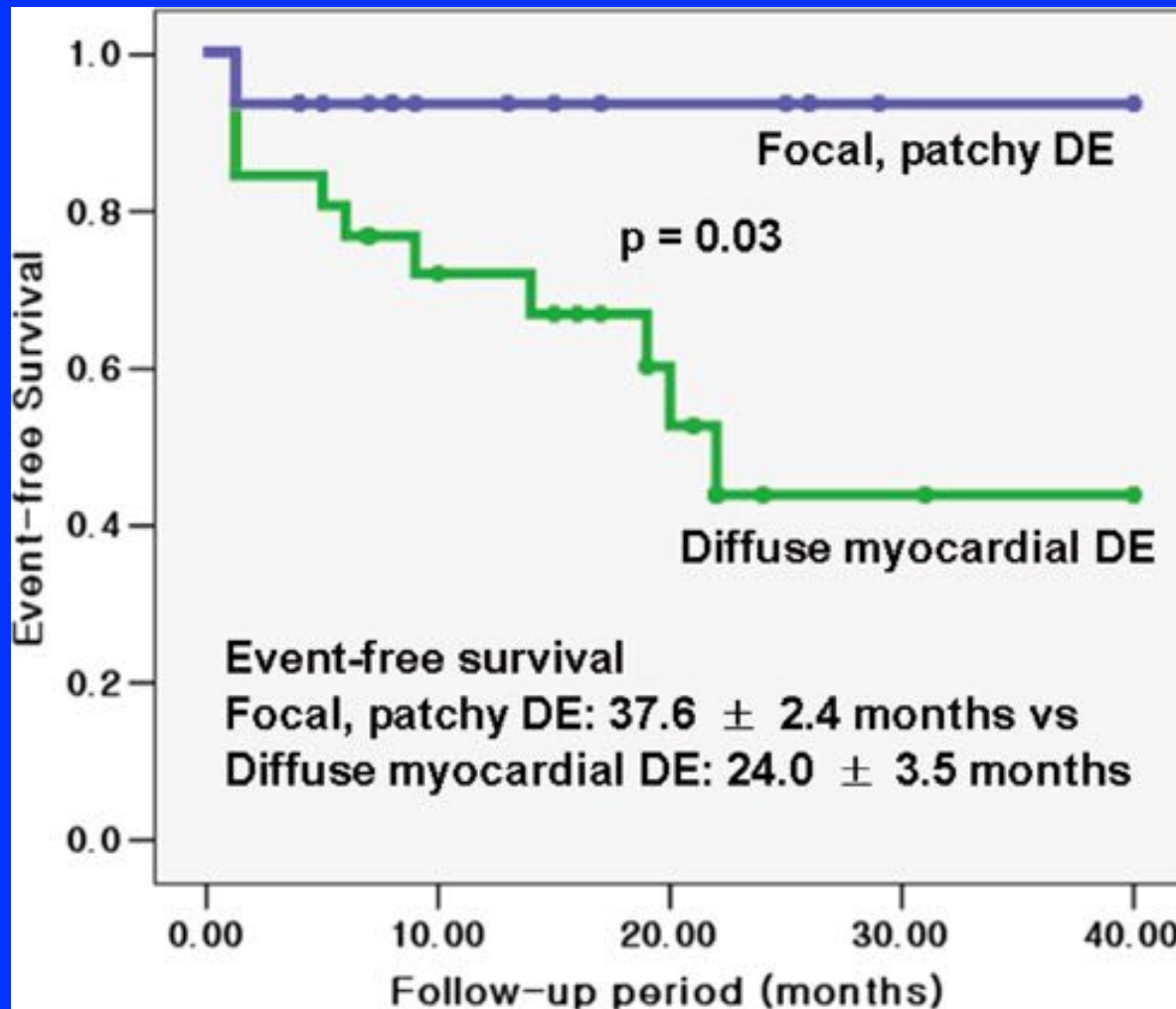
- In 26 patients with IDC
- Midwall scar with $> 25\%$ scar transmuralities was associated with inducible VT
 - OR 9.1, $P=0.02$ (multivariate analysis)



Midwall Fibrosis Implications

- Wu et al – In 65 DCM patients followed for median 17 months: Midwall scar
 - Was present in 42%
 - Was associated with CHF hospitalization, ICD firing, or cardiac death (HR 8.2, $P < 0.01$)
- Assomull et al – In 101 DCM patients followed for 658 \pm 355 days: Midwall scar
 - Was present in 35%
 - Was associated with all-cause death and hospitalization (HR 3.4, $P = 0.01$)
 - Was associated with sudden death or VT (HR 5.2, $P = 0.03$)

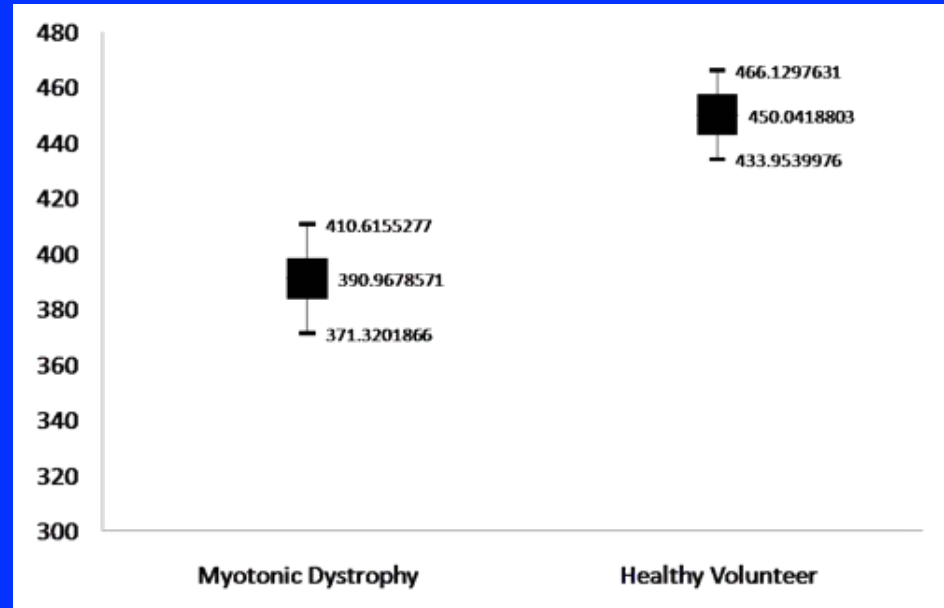
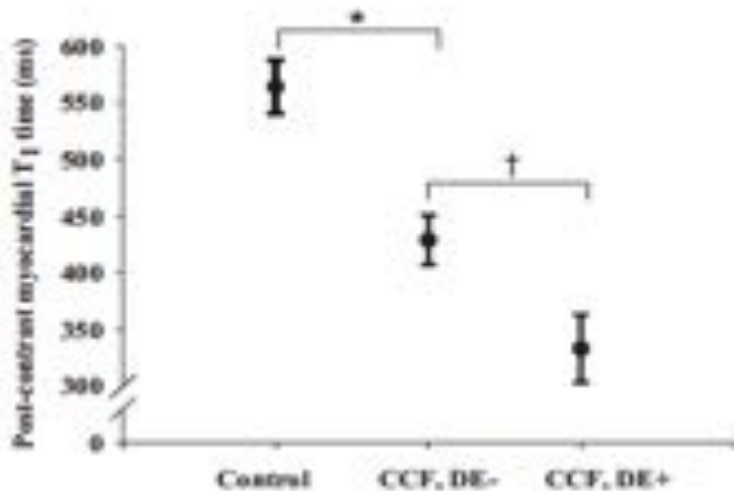
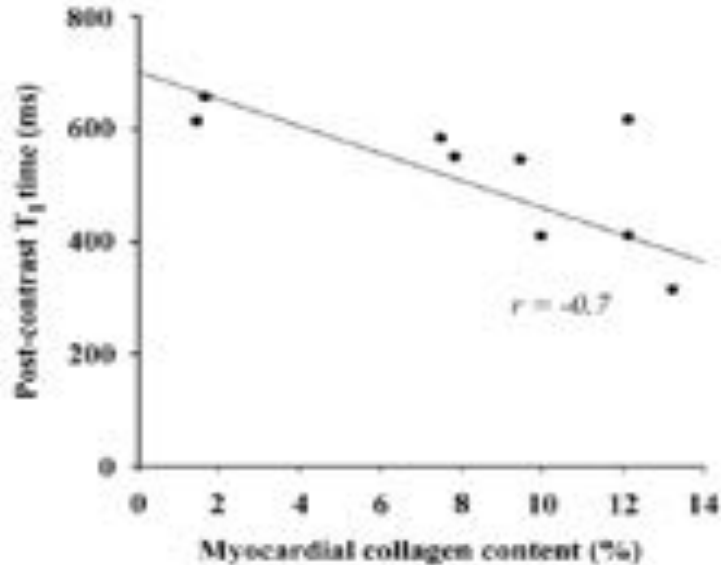
Scar Pattern Predicts Event-Free Survival



- 79 patients
- No ICDs
- EF 25-28%

T1 Mapping

Correlates with normal and abnormal myocardium



Iles, Taylor, et al. J Am Coll Cardiol 2008;52:1574-80

Turkbey, Nazarian, et al AHA 2011

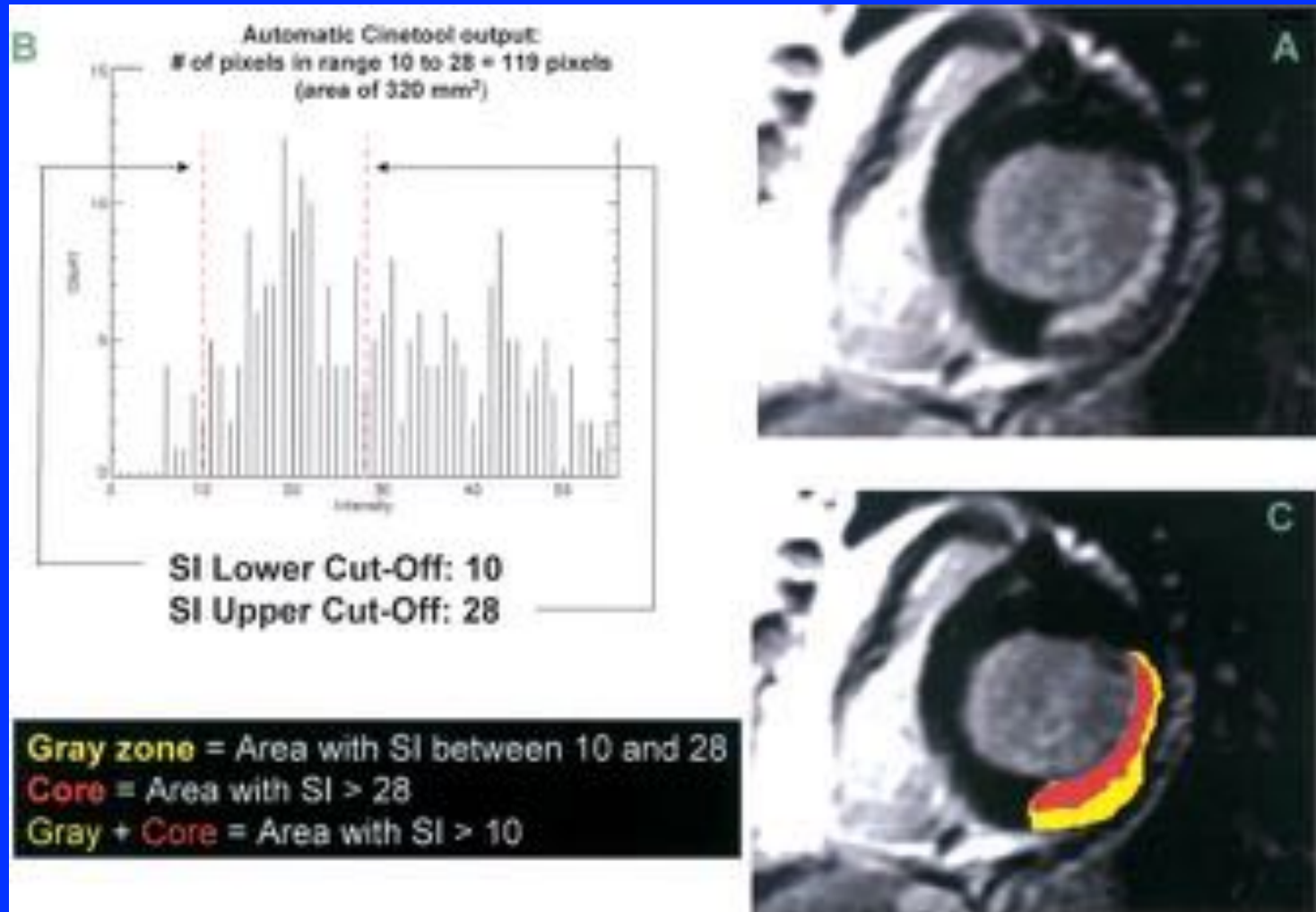
Jellis, Marwick, et al Circ Cardiovasc Imaging. 2011;4:693-702

Ischemic Cardiomyopathy

Hyperenhancement may not have
uniform intensity

Gray Zone:

Intermediate level of hyperenhancement



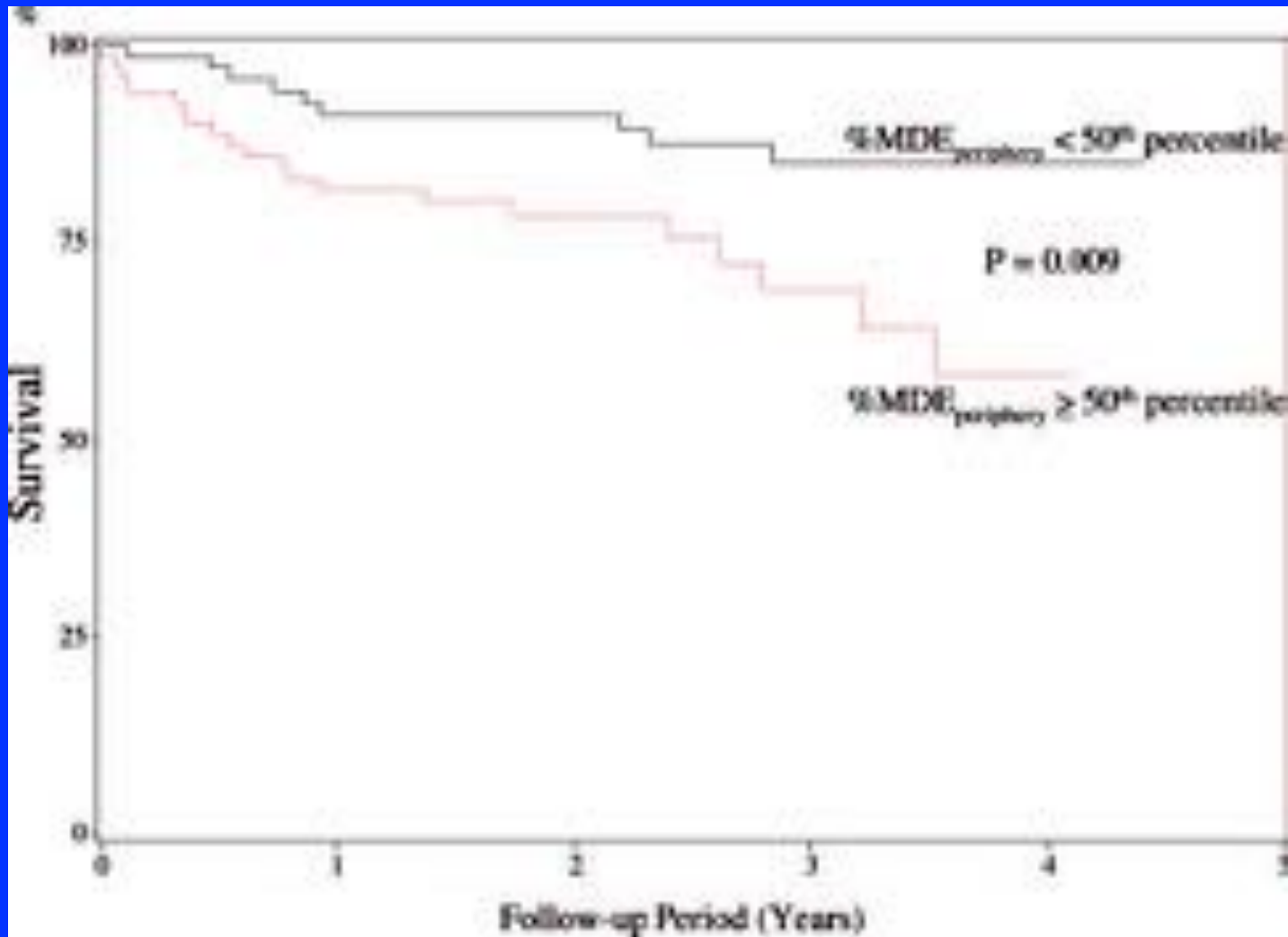
Extent of Gray Zone Predicts Inducibility

Schmidt et al, Circulation. 2007;115:2006-2014

TABLE 2. MRI Indices According to Inducibility Status at Electrophysiology Study

Variable	Noninducible (n=27)	Inducible (n=20)	P
MRI LVEF	0.30±0.10	0.29±0.07	0.79
LV end-diastolic volume, mL	220±70	228±57	0.68
LV end-systolic volume, mL	156±61	162±44	0.71
LV end-diastolic mass, g	146±46	132±30	0.23
Infarct location, n (%)			0.23
Anterior±other territory	15 (56)	15 (75)	
Inferior and/or lateral only	12 (44)	5 (25)	
Transmural infarct extent: % of sectors grouped by quartiles of transmurality			
No infarct	51±15	45±9	0.11
1% to 25% infarct transmurality	8±4	7±2	0.61
26% to 50% infarct transmurality	8±3	8±5	0.88
51% to 75% infarct transmurality	11±5	12±5	0.39
76% to 100% infarct transmurality	23±14	28±11	0.17
Extent of hyperenhancement, g			
Total (core+gray)	34±17	40±11	0.17
Infarct core	21±10	21±5	0.95
Gray zone	13±9	19±8	0.015

Extent of Gray Zone Predicts Survival

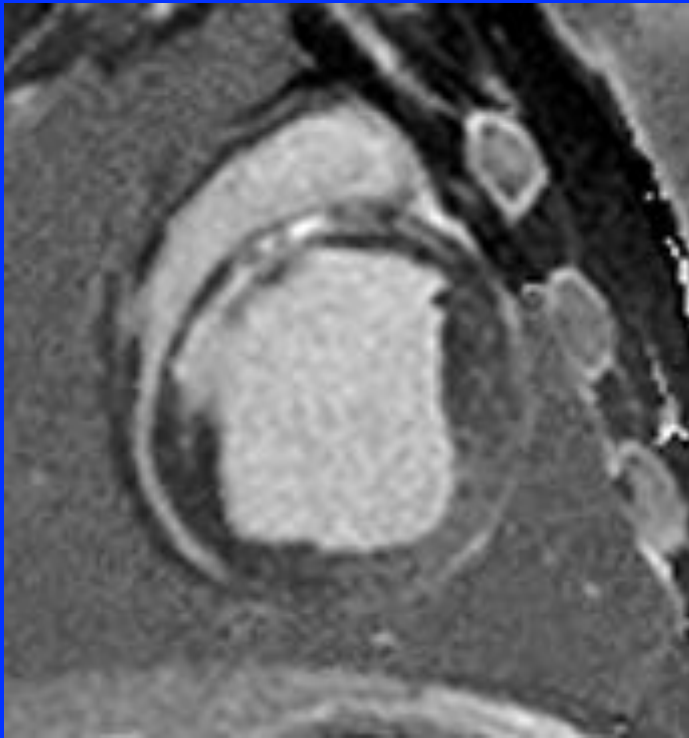


- 144 patients with CAD
- No ICD's
- Mean EF 42-45%

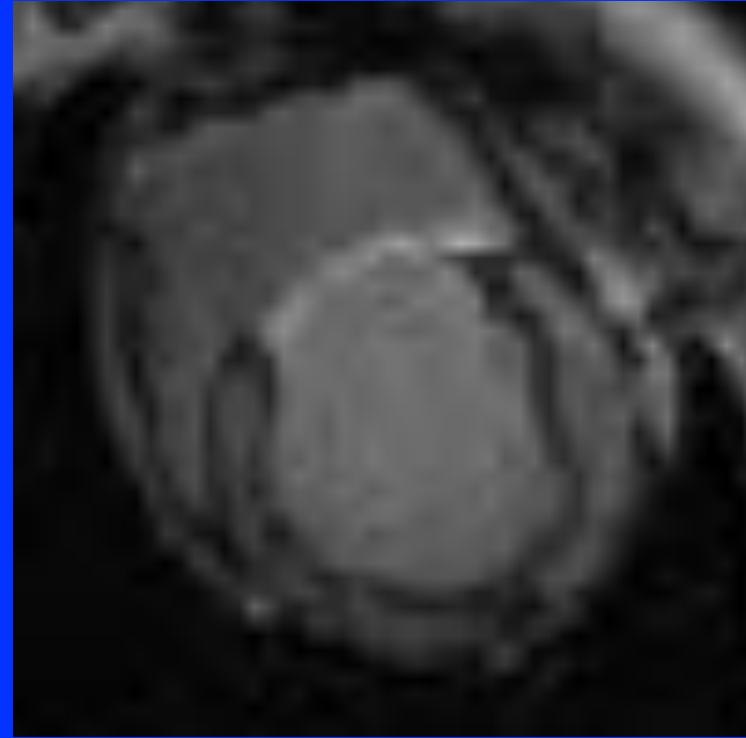
What is the Gray Zone?

Is it the target for VT ablation?

10 Week Swine Infarct Model: Inducibility Correlates with Gray Zone



- Inducible VTs in 8 of 17 pigs
- Gray Zone: 21 ± 8 % infarct

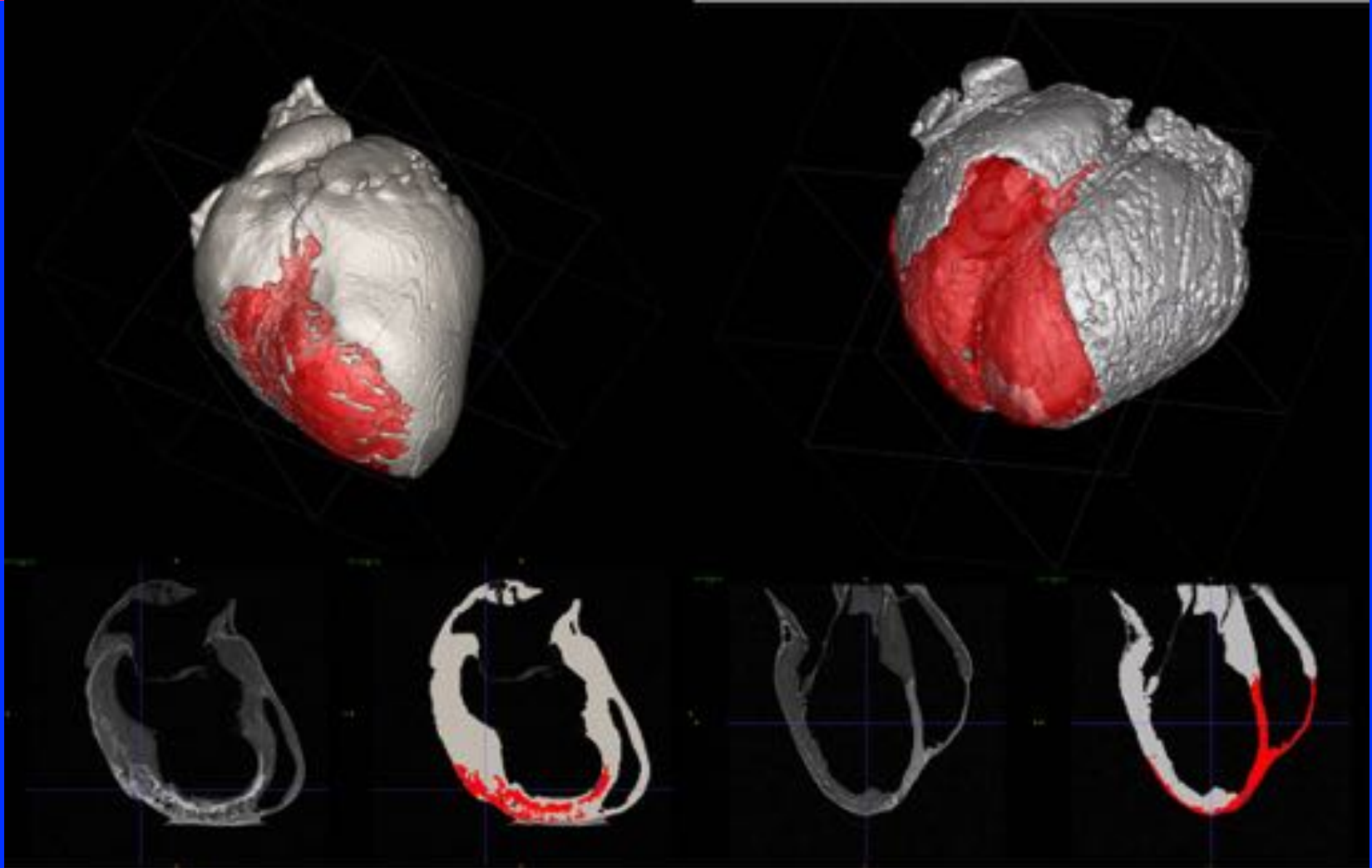


- Non-Inducible in 9 of 17 pigs
- Gray Zone: 12 ± 3 % infarct

$p < 0.009$

Gray Zone = Tissue Heterogeneity

High Resolution MRI (0.4x0.4x0.4 mm voxels)



Inducible

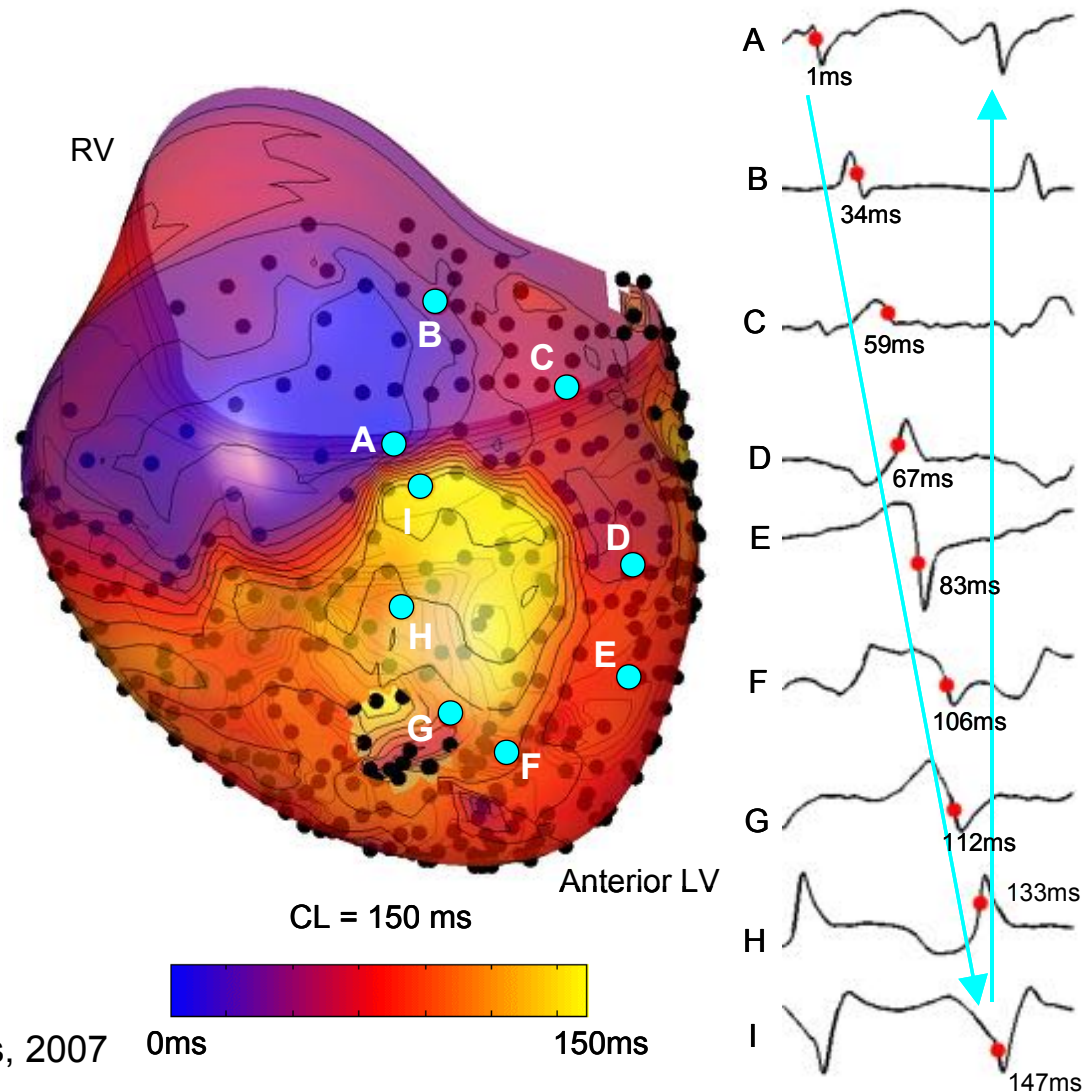
Non Inducible

What do the images tell us about
the mechanisms of VT?

Can they identify the critical VT pathway?

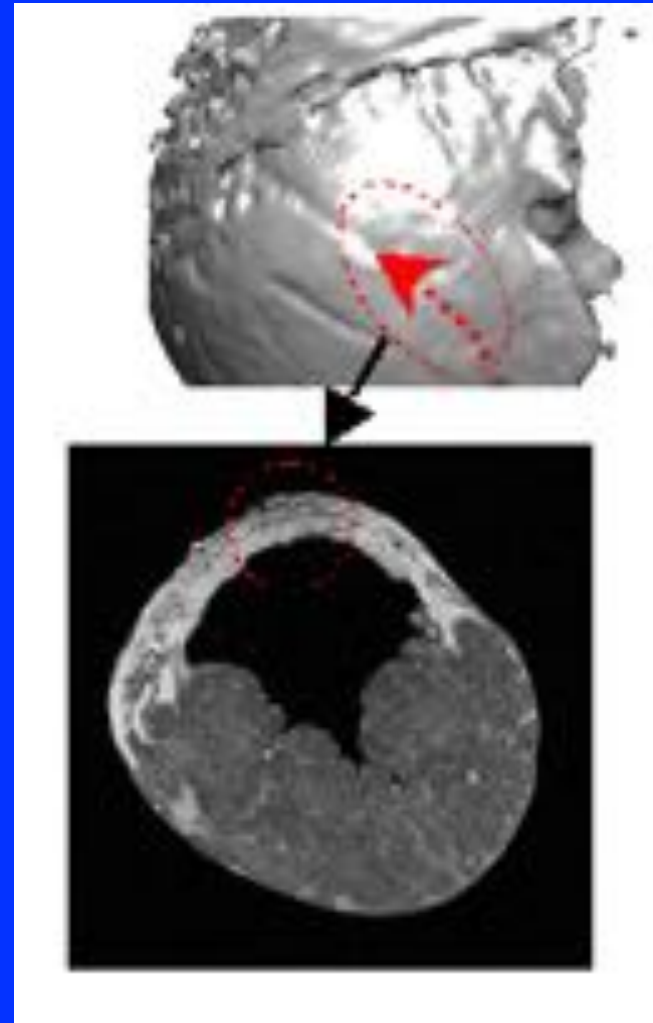
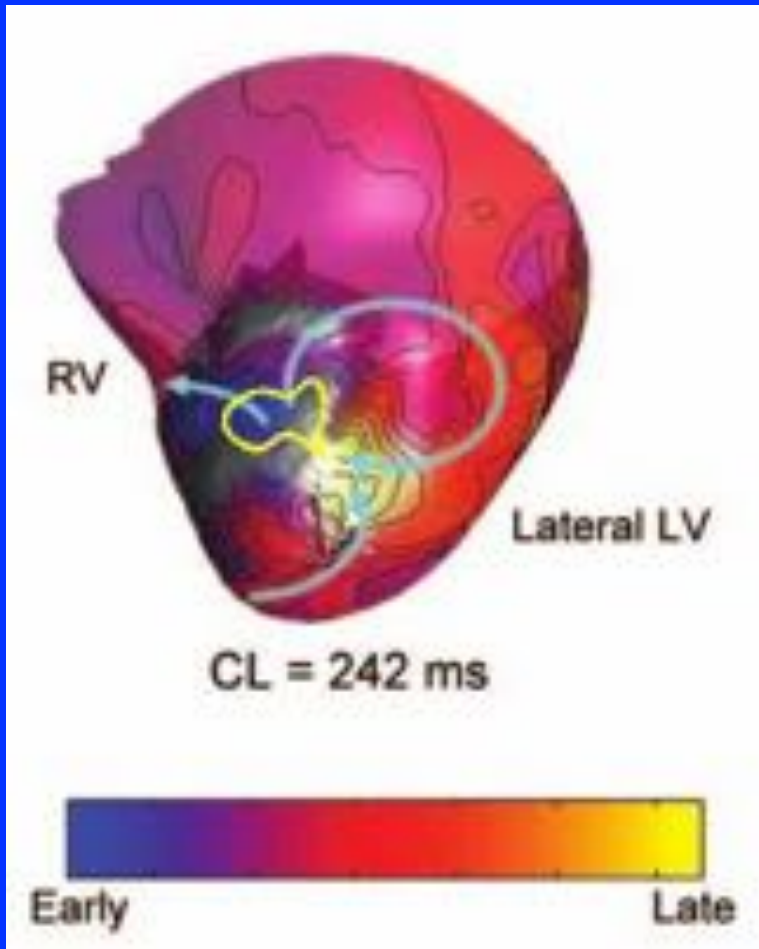
Epicardial Electrograms during VT

Recordings from Multielectrode Epicardial Sock (Swine Infarcts)



Epicardial Reentry Registered with Scar:

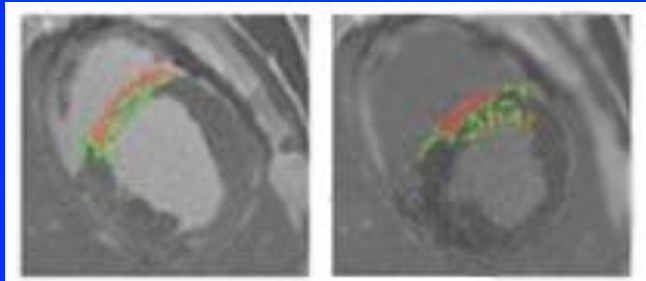
Reentry Through Viable Tissue in Scar



Is the Gray (Heterogeneous) Zone
identified on MRI the critical
pathway for VT generation?

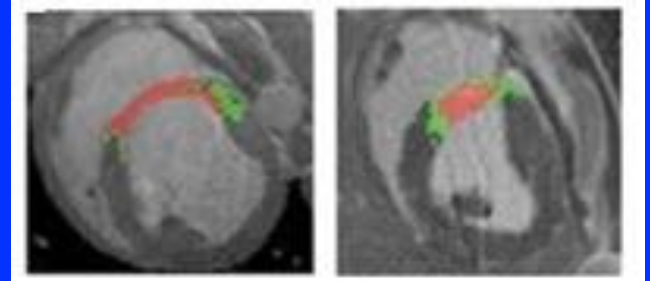
Inducibility Post Ablation

Association with reduction of Heterogeneous Zone

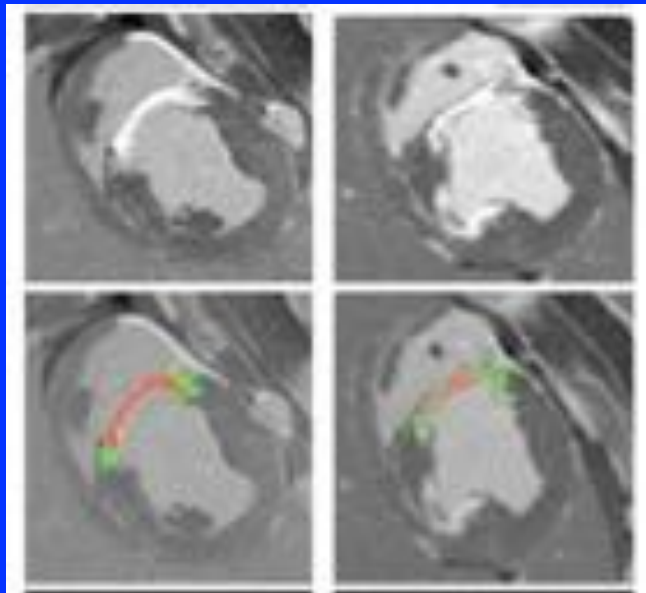


Inducible
Pre-Ablation

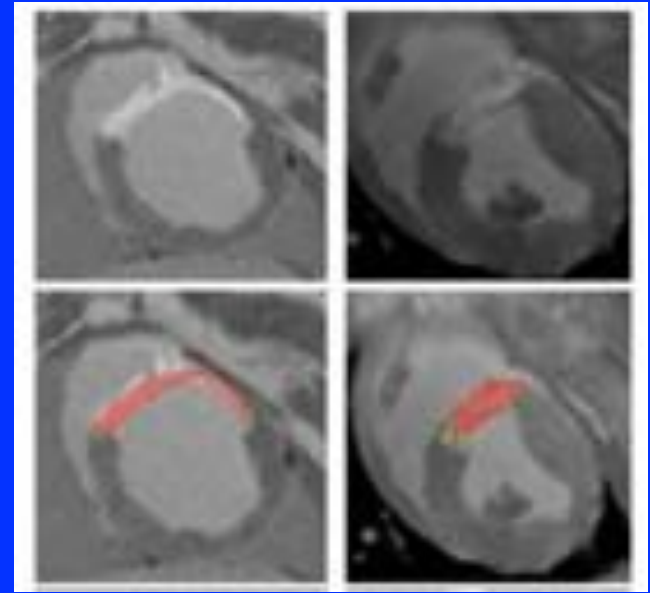
Red = Core
Green = HZ



Post Ablation



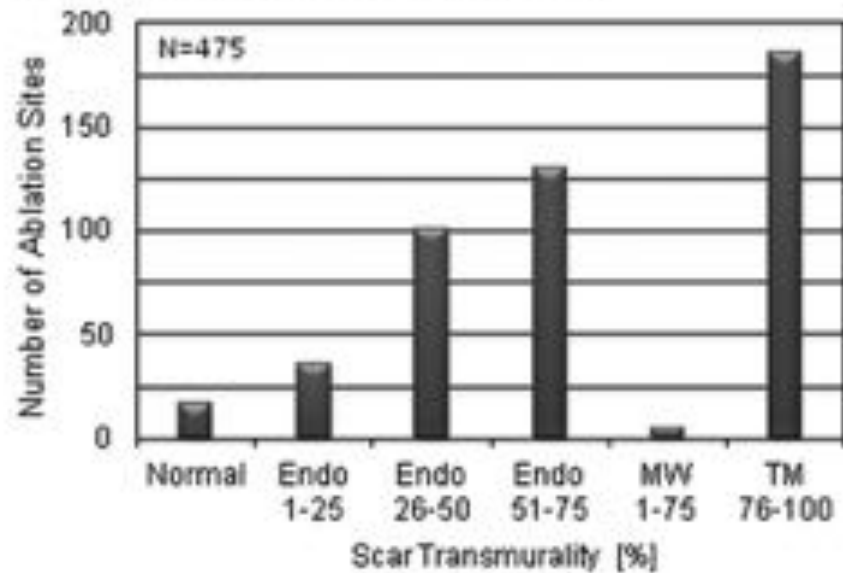
Inducible



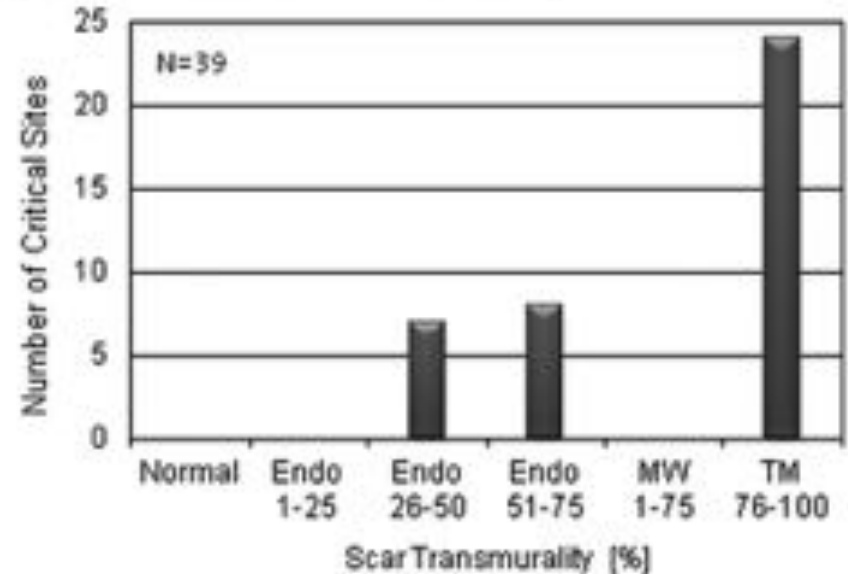
Non-Inducible

Scar Characteristics for VT

A Ablation Sites and Scar Transmurality



B Critical Sites and Scar Transmurality



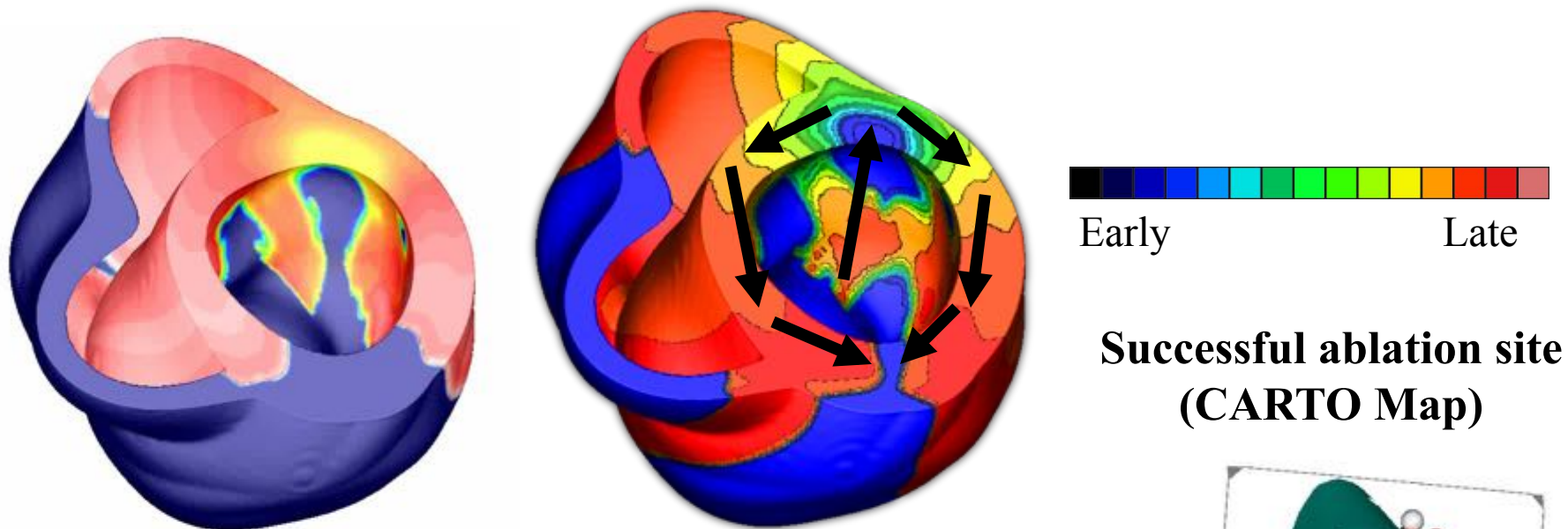
Sasaki, Halperin, Nazarian et al: *Circ Arrhythm Electrophysiol.* 2012;5:1081-1090

Computational Model

Can the VT circuits and ablation targets be predicted?

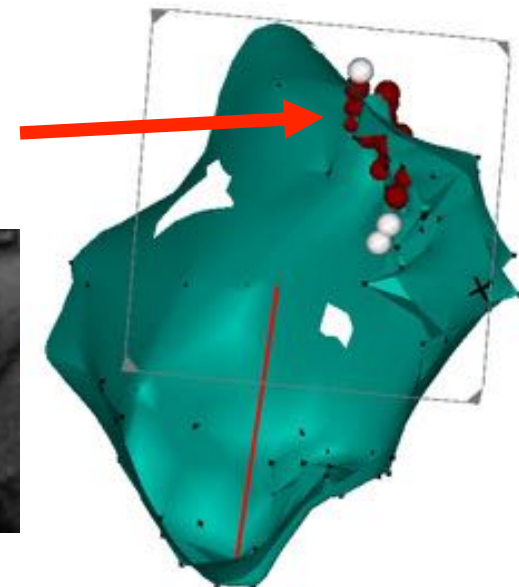
Virtual VT Induction

(Patient#3–Specific Anatomy)



**Successful ablation site
(CARTO Map)**

Basal inferior wall

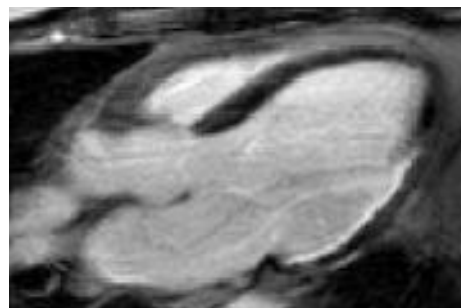
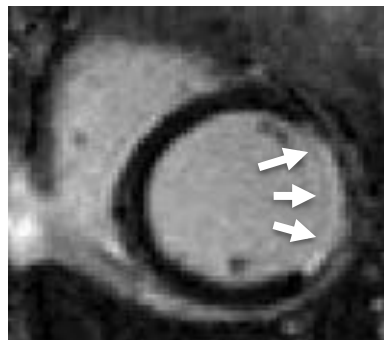


Surface ECG

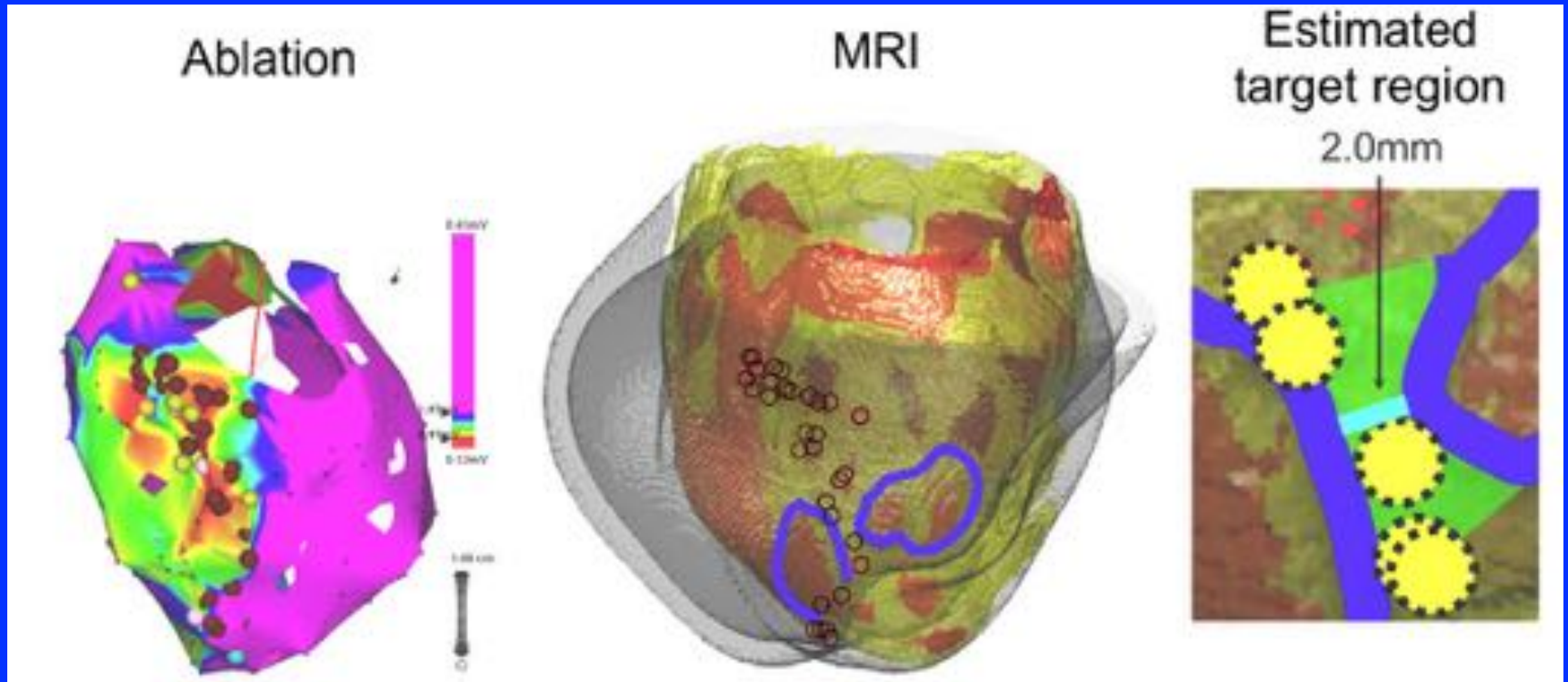
Clinical



Simulated



Success Site vs Predictions (Clinical VT)



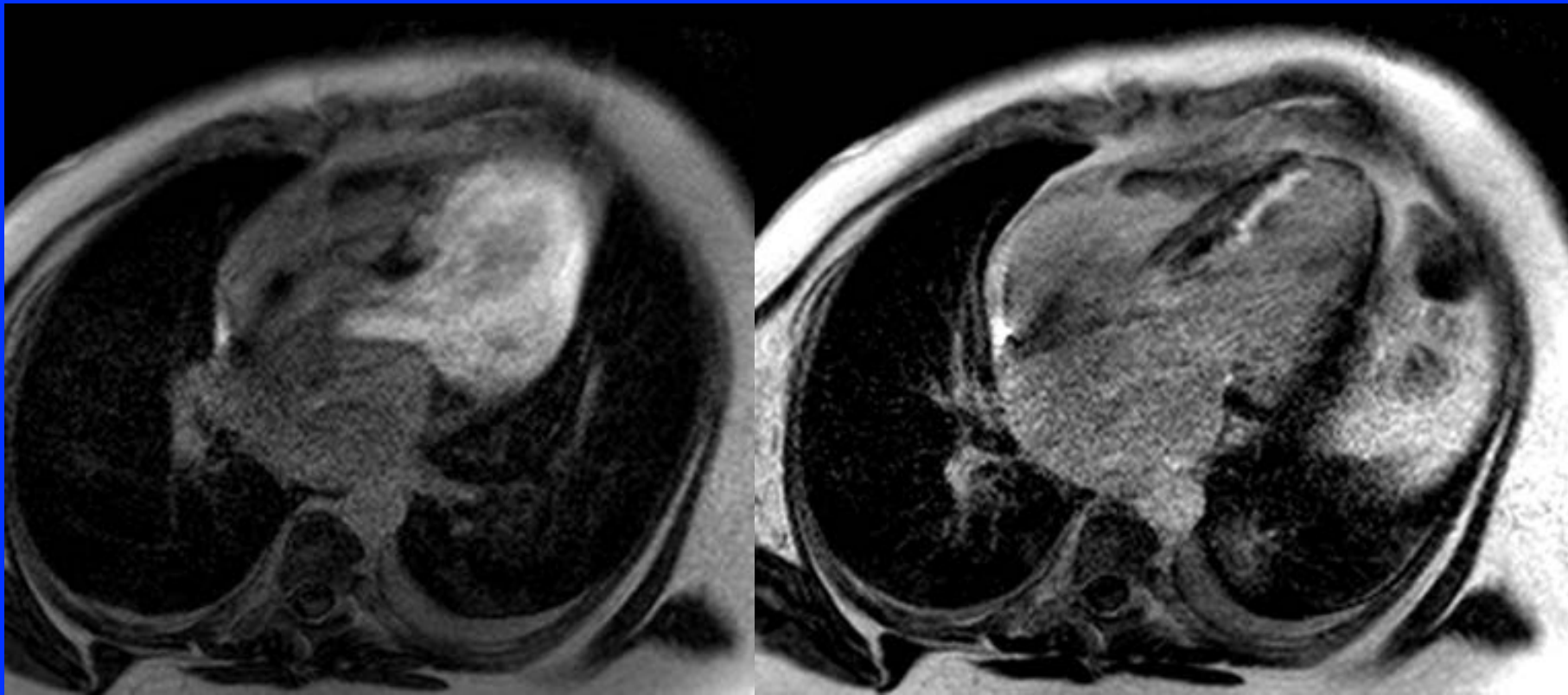
Ashikaga, Halperin, et al: Heart Rhythm, 2013; Aug;10(8):1109-16

ICD artifact has limited the utility
of scar imaging

But can be suppressed

Conventional LGE

Wideband LGE



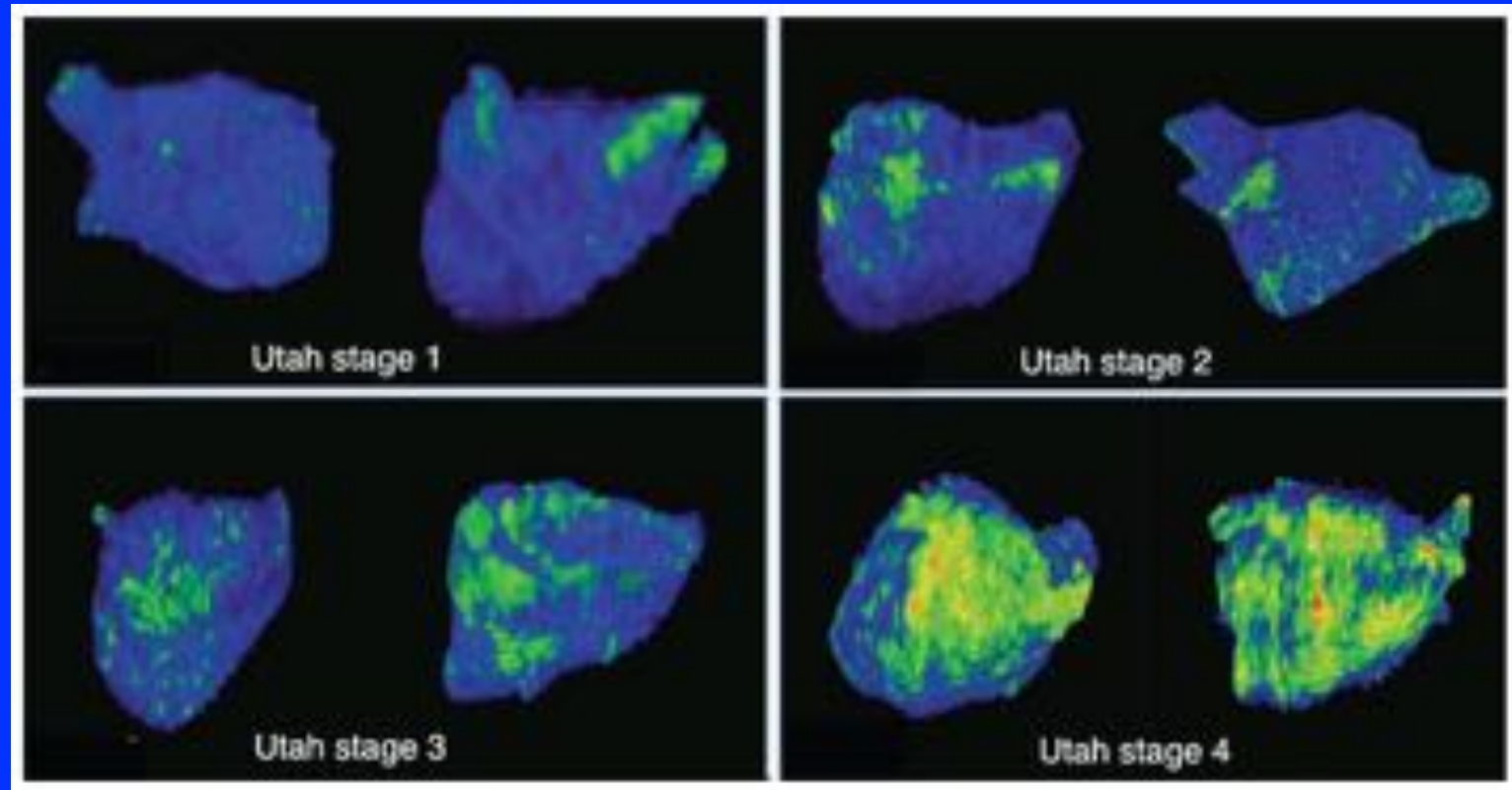
Rashid S, Rapacchi S, Vaseghi M, Tung R, Shivkumar K, Finn JP, Hu P. Improved late gadolinium enhancement MR imaging for patients with implanted cardiac devices. *Radiology*. 2014;270:269-274

Stevens SM, Tung R, Rashid S, Gima J, Cote S, Pavez G, Khan S, Ennis DB, Finn JP, Boyle N, Shivkumar K, Hu P. Device artifact reduction for magnetic resonance imaging of patients with implantable cardioverter-defibrillators and ventricular tachycardia: Late gadolinium enhancement correlation with electroanatomic mapping. *Heart Rhythm*. 2014;11:289-298

Atrial Fibrillation

Atrial Scar can be Present in AF

May be a Mechanism for Persistent AF



Utah stage 1: <5% fibrosis, Utah stage 2: 5–20% fibrosis,
Utah stage 3: 20–25% fibrosis, Utah stage 4: >35% fibrosis.

Atrial Scar Correlates Inversely with Success from Catheter Ablation of AF

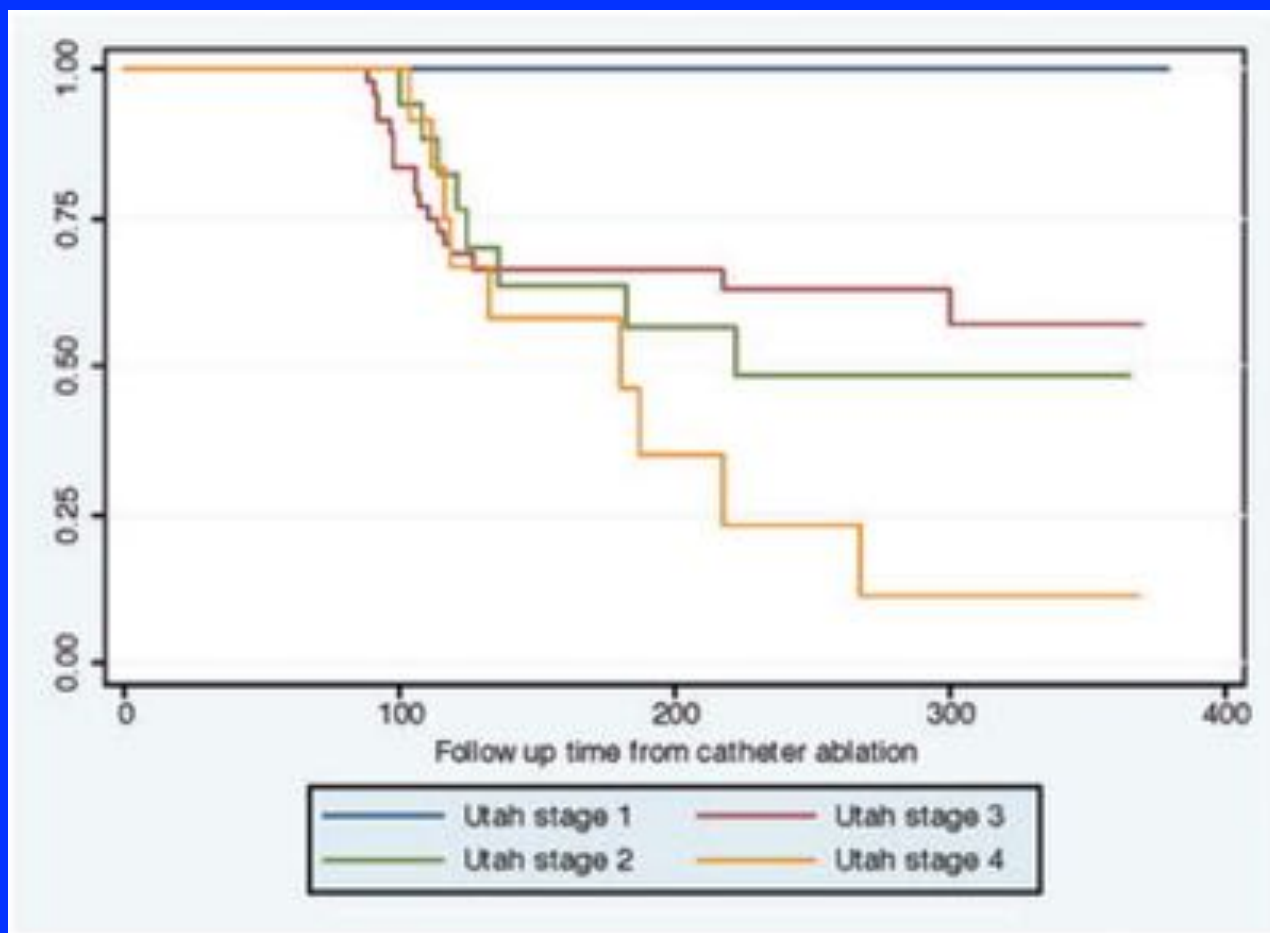
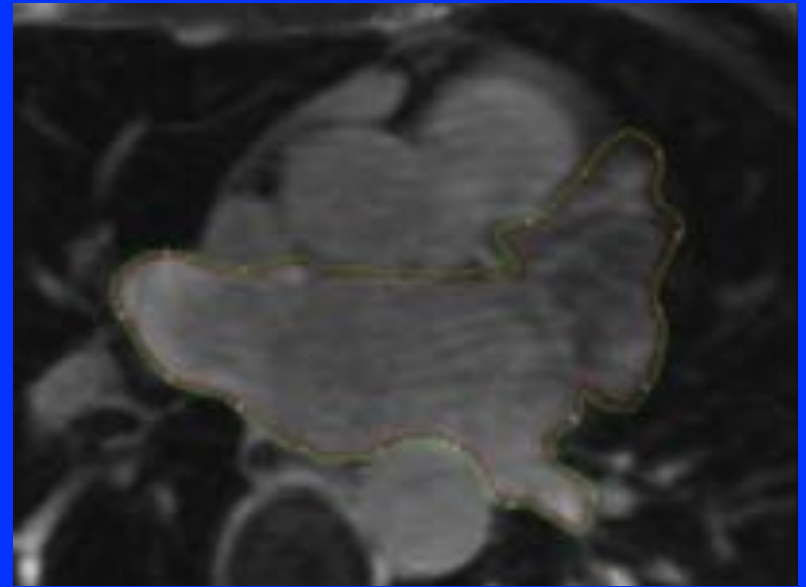
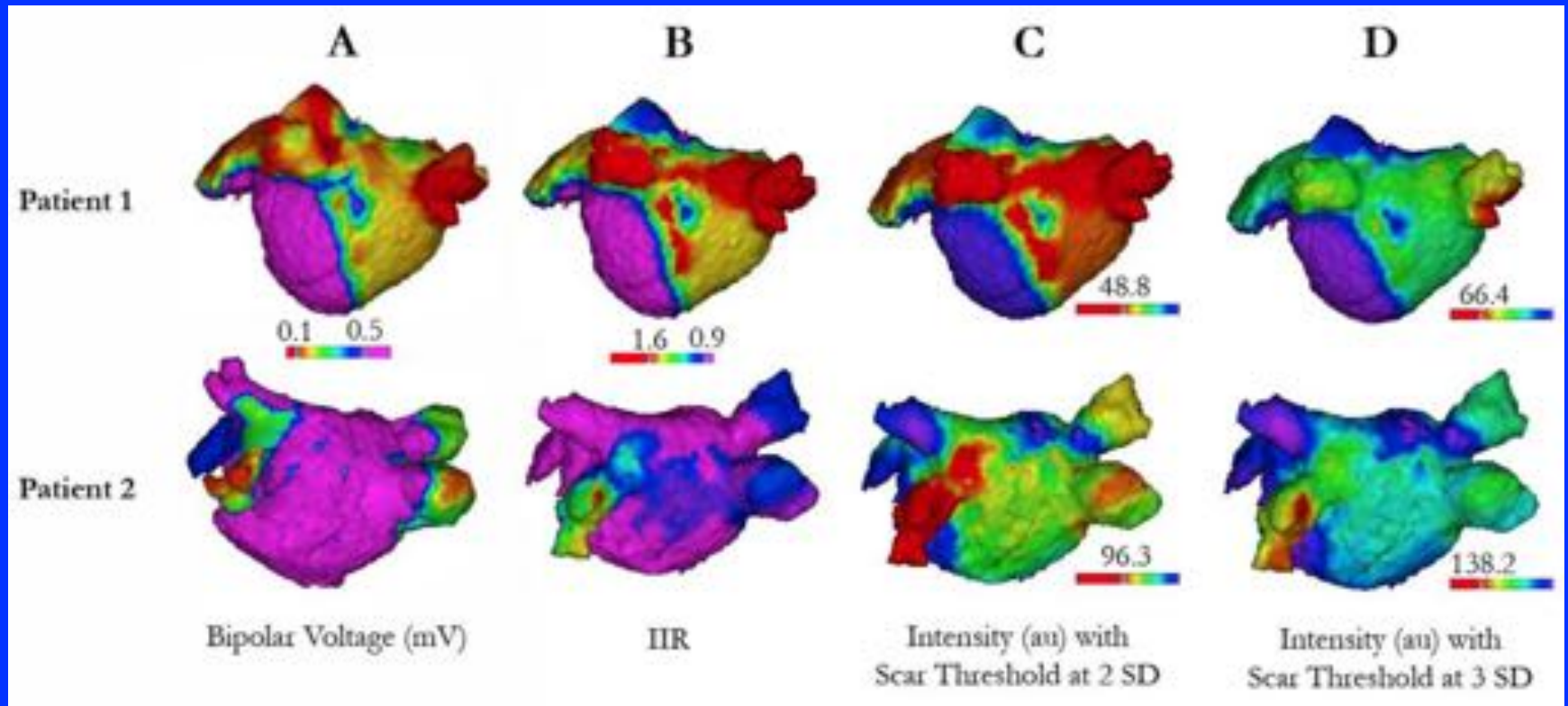


Image Intensity Ratio (IIR) as Surrogate of Scar

- The atrial myocardium is divided into 20 sectors per plane
- The signal intensity of each sector is then divided by the mean blood pool image intensity
- The IIR is a normalized measure of intensity

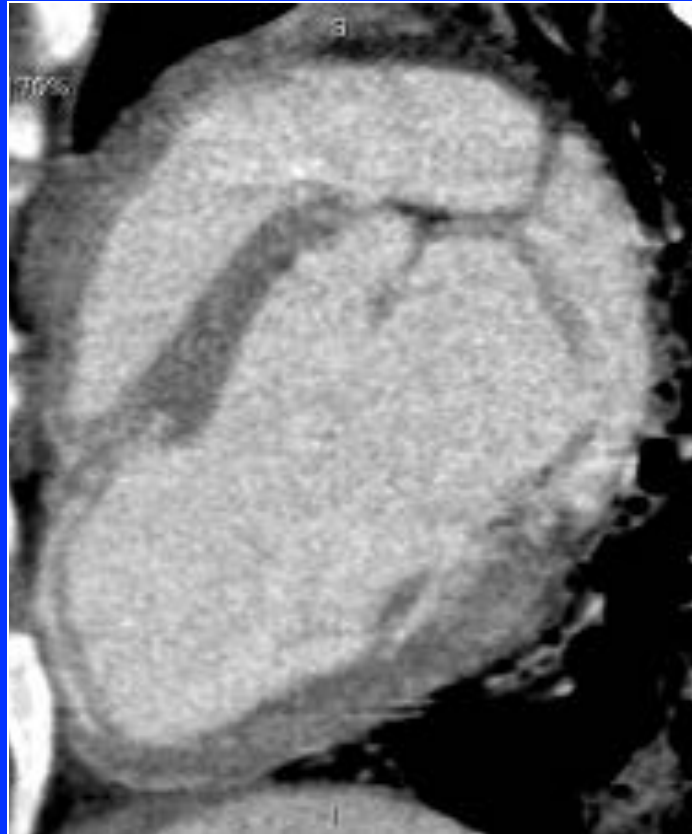


IIR as Surrogate of Scar



What about CT?

Imaging of Scar with CT



8 weeks
post infarct

Courtesy Dr Lardo

Summary

- Delayed enhancement MRI can accurately identify detailed anatomy of scar
- The critical zones for occurrence of VT in ICM, and targets for ablation, are likely areas of tissue heterogeneity that can be imaged with MRI
- Computational modeling, based on high-resolution MR imaging, may accurately identify critical VT targets
- Delayed enhancement MRI can be used to quantify the scar burden in the atrium and may help in defining prognosis
- With proper timing of contrast, scar can be imaged with CT

Investigators

- Hiroshi Ashikaga
- Ergin Atalar
- Roy Beinart
- Ronald Berger
- David Bluemke
- Paul Bottomley
- Hugh Calkins
- Fady Daoud
- Timm Dickfeld
- Jun Dong
- Yoav Dori
- Heidi Estner
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- Daniel Herzka
- Ritsushi Kato
- Lars Lickfett
- Aravindan Kolandaivelu
- Jennifer LaCorte
- Albert Lardo
- Joao Lima
- John McManigle
- Elliot McVeigh
- Glenn Meininger
- Frank Miller
- Saman Nazarian
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- Natalia Trayanova
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